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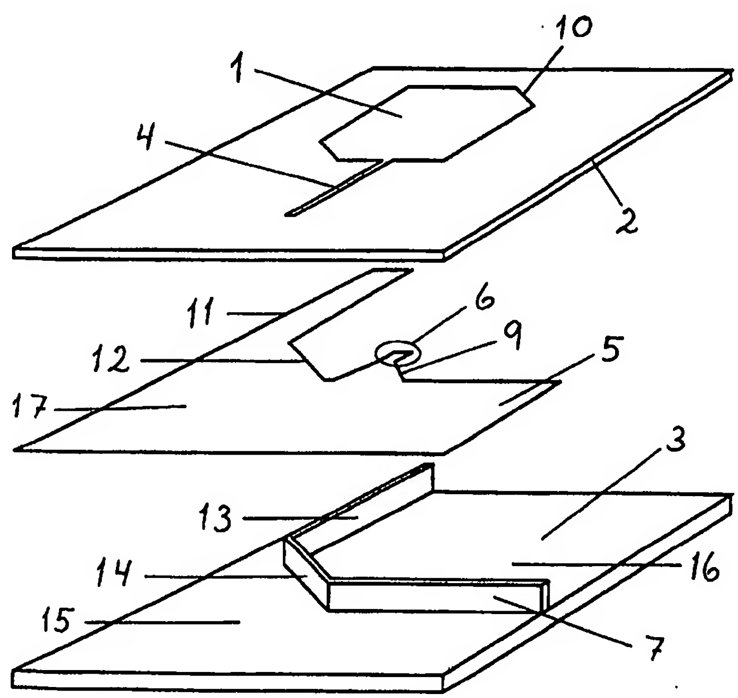
(54) Title: ANTENNA AND METHOD USING TUNING STUB

(57) Abstract

A microwave antenna comprises a dielectric substrate (2) with an emitter element (1) and a feed line (4) to the emitter element, and on the substrate underside there is a ground plane (5) for the feed line (4). A separate ground plane for the emitter element (1) is arranged at a larger distance from the substrate (2), and the two ground planes (3, 5) are interconnected electrically (7). The feed line ground plane (5) is shaped with a tuning section (6) extending somewhat in underneath the emitter element, and the tuning section (6) is connected to the rest of the feed line ground plane via a transition section (9). This antenna can be manufactured at low cost, and gives good tuning possibilities for the feed line/emitter element connection.



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ANTENNA AND METHOD USING TUNING STUB

The present invention relates to an antenna for electromagnetic radiation, preferably in the microwave range. The antenna comprises a dielectric substrate having on one side thereof (top) at least one emitter element of a conducting material, as well as at least one feed line leading to the emitter element. On an opposite side (underside) the dielectric substrate has a ground plane for the feed line, and the antenna is also equipped with a separate ground plane for the emitter element, arranged at a distance from the substrate. Such an antenna type is previously known, as will be apparent from the following:

So-called microstrip antennas were first put into the use in the mid-sixties, especially for missiles and aircraft applications. Initially the microstrip patches were used as individual radiators/emitter elements, but they are now often elements in arrays to provide fixed beams as well as scanning beams.

Today there is a lot of industrial research and development on microstrip antennas, where the goal is to have more innovative designs to fulfil operational demands, at the same time coupled with reliable manufacturing methods. The driving force is to obtain low cost, low weight and low profile antennas for use in modern communication systems, in military systems and for other applications.

This antenna type is described in a relatively comprehensive manner in "Handbook of microstrip antennas", vol. 1 and 2, J. R. James and P. S. Hall, Peter Peregrinus Ltd., London, 1989, ISBN 086341 150 9, which publication contains an extensive collection of works from different authors.

The generic microstrip antenna consists of a metallic patch arranged above a conductive ground plane, and with a dielectric substrate therebetween. The patch (the radiation element) is fed with a feed voltage V_f relative to ground at an appropriate point, as shown in fig. 1.

Emission from the radiation element may take place with numerous possible geometrical patch shapes, and thus there is large freedom concerning such geometrical design. However, usually certain special geometries are used. One such shape is a rectangular or square patch, as shown in fig. 2a, b, c, but the feeding up to the radiation patch takes place in different manners in these three

prior art cases. In fig. 2a the emitter element 1 is fed in a coplanar manner via a feed line 4, and only one single substrate 2 is used above a (not shown) ground plane. Also in fig. 2b the emitter patch 1 lies upon a substrate 2, and with the ground plane 3 therebelow, but the feed line 4' enters in the form of a coaxial line with a center conductor passing through the substrate 2 up to the radiation patch 1. In fig. 2c there appears two substrates 2 and 2" on respective sides of a ground plane 3. The ground plane 3 has an opening or aperture 8 which is located underneath the emitter element 1, and underneath the aperture 8 there is a feed line 4", i.e. this feed line is shown as lying on the underside of the substrate 2". In other words, the aperture coupled antenna has a multilayer structure.

Another geometrical shape of the patch/emitter element that is in common use, is a circular shape, not shown here in any drawing.

Circular polarization can be obtained by means of orthogonal feed lines in toward the emitter element and with 90° phase shift therebetween. Optionally, circular polarization can be obtained by means of a perturbation of the actual patch geometry, e.g. by corner cutting or incorporating slots.

Two of the major problems associated with microstrip antennas are that they exhibit small bandwidths and high loss (in particular this concerns feed and network losses in arrays). Use of a thicker substrate underneath the emitter element, and/or a substrate having lower permittivity may increase bandwidth as well as radiation efficiency. With the appropriate substrate, radiation efficiency of about 95% is achievable for a single patch antenna.

However, increasing the substrate thickness causes some feeding problems. With coplanar feed (compare fig. 2a), increased substrate thickness also increases the radiation from the feed network, which has a degrading effect on the antenna performance. The width of the feed lines also increases, which may lead to a space problem in arrays.

The coaxial type feed (also named "probe feeding"), see fig. 2b, requires special matching arrangements between the feed line and the emitter patch in order to compensate for the probe inductance and to reduce the return loss. The probe feed arrangement is also more expensive to manufacture, as it comprises a connection through the substrate.

In general, it is desirable to have a substrate with low permittivity and good thickness underneath the radiation element/patch, and a thin, rather high permittivity substrate underneath the feed line. By using different substrates for the feed line and the patch, such as shown in fig. 2c, one has the possibility to separately optimize the emitter patch and the feed line. The two main disadvantages with this multilayer structure is, however, increased cost regarding both materials and manufacture.

From T. Murata and K. Ohmaru, "Characteristic of circularly polarized printed antenna with two-layer structure", IECE Japan Technical Report, AP86-101, I996 (Japanese language) is known a solution where the feed and patch substrates have different thicknesses in order to increase the bandwidth and decrease the feeder loss. However, this solution is relatively expensive because the feed line ground plane is fabricated separately in relation to the printed antenna element. Nor is tuning of the connection between feed line and patch possible in this solution.

Thus, there exists a need for a microstrip antenna that can be manufactured in a simple and inexpensive manner, and which at the same time provides a performance similar to the performance of a two-layer aperture coupled antenna.

The present invention aims at fulfilling this need. Therefore, in accordance with the invention, an antenna is provided of the type mentioned initially, and which in addition has the special feature that the feed line ground plane is shaped with a tuning section extending some distance under the emitter element, the tuning section being connected to the rest of the feed line ground plane via a transition section. This solution results in manufacturing costs similar to the costs for the simple and coplanar feed antenna having one substrate (fig. 2a), and feed line performance corresponding to the performance of the two-layer aperture coupled antenna (fig. 2c). Additionally, in accordance with the invention, a possibility is provided for implementing a simple, capacitive tuning method for the connection between the emitter element and the feed line.

In accordance with a preferred embodiment of the invention, the transition section up toward the tuning section is shaped with a gradually decreasing width. The taper may be linear or have some other geometrical shape, e.g. a curved taper.

Preferably the transition section borders to and passes into the tuning section in a region near an edge of the emitter element where the feed line enters.

In a preferred embodiment the substrate, the emitter element and the ground planes are flat and parallel. However, it shall be remarked that it is not necessary with a flat embodiment.

The radiation element, the feed line and the feed line ground plane can be fabricated by etching a dielectric substrate that is metal coated on two sides. Such etching is a favorable manner of fabricating, however other methods can also be utilized in the manufacture. In a preferred embodiment, the antenna tuning section (tuning stub) is substantially rectangular.

In a favorable embodiment the two ground planes are interconnected by means of a wall of a conductive material. Such a wall solution is favorable because it provides "many short-circuiting spots". A suitably thin wall also reduces material consumption and weight, relative to a solution with a bulk type connection between the larger part of the feed line ground plane and an extension of the emitter element ground plane. Such a bulk type connection is of course another possible design, and the emitter element ground plane can then be formed by milling out a section from a suitably thick and conductive material. The previously mentioned wall is preferably perpendicular to both ground planes when these planes are parallel. However, this is not a necessity for the invention.

Preferably the wall is placed and adapted geometrically so that the transition section and the tuning stub protrude like a section that has been cut off from the rest of the feed line ground plane by means of the wall.

When the radiation patch ground plane is situated underneath the substrate, an interspace between the substrate and the radiation patch ground plane may be filled by a dielectric material, at least in an area underneath the radiation patch and the tuning stub. The dielectric material may e.g. be a plastic material, or it may be e.g. air.

When a wall provides a connection between the two ground planes as mentioned above, the complete section that is bounded by the wall, the emitter element ground plane and the substrate and which partly lies underneath the emitter element, may be filled by the dielectric material. In a more detailed embodiment of the invention, the substrate may have

- a number of emitter elements/radiation patches arranged in a predetermined pattern,
- a feed line network,
- a common ground plane for the emitter elements, and
- a common ground plane for the feed line network,
- where each respective emitter element has a corresponding assigned tuning section in the common ground plane for the feed line network.

The invention also comprises a further aspect, namely a method for tuning the match between a feed line and an emitter element in an antenna of the type discussed above. The method comprises the special features that the length of a tuning section is determined from impedance calculations and a requirement that the impedance that is constituted by impedance contributions from the tuning section and the emitter element, shall be purely resistive at a particular frequency, and that the tuning section is provided with the length thus determined, when manufacturing the antenna. The manufacturing process may comprise an etch process or e.g. milling or cutting conductive/metallic material.

In the following the invention shall be described in more detail by means of a discussion of embodiment examples, and it is at the same time referred to the appended drawings, where

fig. 1 shows the generic and previously known microstrip antenna design,

fig. 2a shows a previously known design with coplanar feed on one single substrate,

fig. 2b shows a previously known design with a feed line passing through the substrate,

fig. 2c shows in an exploded view a previously known design with coupling from an underlying feed line through an aperture in the emitter element ground plane, and with two substrates,

fig. 3 shows an embodiment of an antenna in accordance with the invention, in an exploded view, and

fig. 4 is a circuit diagram representing a transmission line model for the central elements in an antenna in accordance with the invention.

In fig. 3 appears an example of a favorable embodiment of the antenna in accordance with the invention. The antenna is stratified, and is shown suitably in an exploded view. The special antenna shown here, is adapted to emit circularly polarized radiation, and this is done by designing the emitter element/patch 1 with cut corners 10. The top layer also shows the dielectric substrate 2 and feed line 4 leading to the emitter element 1. Underneath the substrate 2 one finds the feed line ground plane 5. This ground plane 5 has a special shape with a tuning section 6 protruding some distance in under the radiation patch 1, and a transition section 9 tapering gradually toward the tuning section 6. The tuning section 6 behaves approximately in the same manner as an open-ended stub where the stub length determines the reactance. In order to obtain low return loss, i.e. maximum power transfer, this stub provides impedance matching together with the width of the feed line 4. The ground plane 5 lies closely under or is fixed to the underside of substrate 2. The feed line ground plane further comprises a main part 17 and a protruding part 11, where part 11 and diagonal edge 12 are provided to give a geometrical adaptation to the shape of the radiation patch 1, namely with a uniform distance to the edges thereof, and at such a distance that the emission characteristics are unaffected. Besides, as regards matching/adaptation, the extent of ground plane 5 is without importance, the area may in principle be infinite.

A ground plane for the actual emitter element 1 is constituted by part 3, which is a metallic or conductive plate at a larger distance from the emitter element than the distance between ground plane 5 and the feed line. This distance is maintained by the conductive wall 7, which wall also provides a conducting interconnection between the two ground planes and provides short-circuiting of undesirable modes. The wall height can be adapted/adjusted. The conductive wall 7 is appropriately designed with a diagonal part 14 and a protruding part 13 in order to provide distance adaptation to the emitter element 1,

i.e. wall parts 13 and 14 are arranged at the same distance from the emitter element edge, however not so close as to affect the emission characteristics. Reference numeral 15 designates the remaining part of ground plane 3, actually there might as well have been a bulk metal connection on this side of wall 7 up to the feed line ground plane 5, but such a bulk metallic connection would mean large material consumption.

It is to be noted that this planar design of an antenna with two ground planes, can be extended in a simple manner to an array antenna having several emitter elements/radiation patches.

Capacitive antenna tuning can be made by adapting the length of the tuning section 6. The transition section 9 can be linearly tapered as shown in the drawing, or a curved shape can be used.

The solution including a wall 7 has been chosen because it is not sufficient with a few short-circuiting spots between the two ground planes, which must be electrically interconnected. Besides, a suitably thin wall also reduces material consumption and weight in comparison to a solution with a bulk connection between the main part 17 of the feed line ground plane 5 and the remaining part 15 of the emitter element ground plane 3.

One method for manufacturing the top part of the shown antenna, is that a dielectric substrate metal coated on two sides is subjected to etching of the metal in order to create the emitter element 1, the feed line 4 and, on the other side of the substrate, the feed line ground plane 5. Other manufacturing methods are of course also possible.

The interspace between substrate 2 and ground plane 3 can possibly be formed by machining this area out from a suitably thick and conductive material, whereby either a bulk connection is obtained from wall 7 and further back in the region above reference numeral 15, or where this region is also machined out so that only the thin wall 7 remains.

It shall be remarked that if wall 7 comes too close to or right under the emitter element 1, this will influence the radiation characteristics in a negative manner. On the other hand, the tuning section 6 may, as mentioned previously,

extend in underneath the emitter element 1. The transition section 9 should reach the edge of the emitter element 1.

To provide desirable characteristics, the area between ground plane 3 and substrate 2, i.e. all the way to wall 7, may be filled by a low-loss dielectric material, e.g. foam polyethylene, polystyrene, PVC or a similar material. The dielectric material may also be air.

A simple method that is often used for impedance matching, is the use of a quarter-wave transformer, and the use thereof is explained in this case with a transmission line model of the feed line 4, the tuning stub 6 and the emitter element/radiation patch 1, referring to fig. 4. The total impedance Z_L at the junction between the feed line 4 and the emitter element 1 can be represented as a parallel connection of two impedances. In fig. 4 the tuning section is given by susceptance jB_s, while the emitter element and the ground plane discontinuity is given by admittance $Y_p = G_p + jB_p$.

Maximum power transfer to the emitter element is obtained by matching Z_{in} to the source impedance (e.g. 50 Ω). This matching is made in a two-stage process.

First, the length of the tuning section is adjusted precisely, so that the reactive part of Y_L is cancelled, which results in a resistive load at a certain frequency. Thereafter, the real part of Y_L is transformed to the desired input impedance via a quarter-wave line having characteristic impedance Z_C. The characteristic impedance of the quarter-wave line is approximately purely resistive, and is determined from its width when substrate type and thickness have been chosen. The input impedance is then given by the expression $Z_{in} = Z^2_c G_p$.

CLAIMS

1. An antenna, preferably for the microwave range, comprising a dielectric substrate (2) having on one side thereof (top) at least one emitter element (1) of a conductive material and at least one feed line (4) leading to said emitter element (1), and having on an opposite side (underside) a ground plane (5) for said feed line (4), said antenna also being provided with a separate ground plane (3) for said emitter element (1) arranged at a distance from said substrate (2) and electrically interconnected with the feed line ground plane (5), characterized in that the feed line ground plane (5) is formed with a tuning section (6) extending some distance in under the emitter element (1), said tuning section (6) being connected to the rest of the feed line ground plane (5) via a transition section (9).

2. The antenna of claim 1,
characterized in that said transition section (9) is gradually tapering toward the tuning section (6).

3. The antenna of claim 2,
characterized in that the transition section (9) borders to and continues into the tuning section (6) in a region near an edge of the emitter element (1) where the feed line (4) enters.

4. The antenna of claim 1, 2 or 3,
characterized in that the substrate (2), the emitter element (1) and the ground planes (3, 5) are flat and parallel.

5. The antenna of one of the previous claims,
characterized in that the emitter element (1), the feed line (4) and the feed line ground plane (5) are formed by etching a dielectric substrate (2) coated by metal on two sides.

6. The antenna of one of the previous claims,
characterized in that the tuning section (6) is substantially rectangular.

7. The antenna of one of the previous claims,
characterized in that the two ground planes (3, 5) are interconnected by means of a wall (7) of conductive material.

8. The antenna of claim 7,
characterized in that the wall (7) is perpendicular to both ground planes (3, 5) which are mutually parallel.

9. The antenna of claim 8,
characterized in that the wall (7) is placed and adapted geometrically in such a manner that the transition section (9) and the tuning section (6) protrude as a part that has been cut from the rest (17) of the feed line ground plane (5) by the wall (7).

10. The antenna of one of the previous claims, where the emitter element ground plane (3) is situated underneath the substrate (2),
characterized in that an interspace between the substrate (2) and the emitter element ground plane (3) at least in an area (16) under the emitter element (1) and the tuning section (6) is filled by a dielectric material.

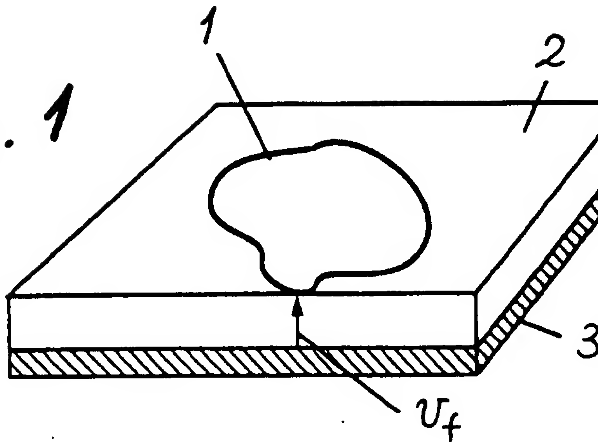
11. The antenna of claims 9 and 10,
characterized in that all of the area (16) bounded by the wall (7), the emitter element ground plane (3) and the substrate (2), and which lies partly underneath the emitter element (1), is filled by the dielectric material.

12. The antenna of one of the previous claims,
characterized in that the substrate (2) has
- a number of emitter elements (1) arranged in a predetermined pattern,
- a feed line network (4),

- a common ground plane (3) for the emitter elements (1), and
- a common ground plane (5) for the feed line network (4),
- where each emitter element (1) has a respective tuning section (6) assigned thereto in the common ground plane (5) for the feed line network (4).

13. A method for tuning the match between a feed line and an emitter element in an antenna of the type indicated in one of claims 1-12, characterized in that the length of the tuning section (6) is determined from impedance calculations and a requirement that the impedance constituted by impedance contributions from the feed line, the tuning section and the emitter element, shall be purely resistive at a certain frequency, and that the tuning section (6) is provided with the length thus determined, when manufacturing the antenna.

Fig. 1



(PRIOR ART)

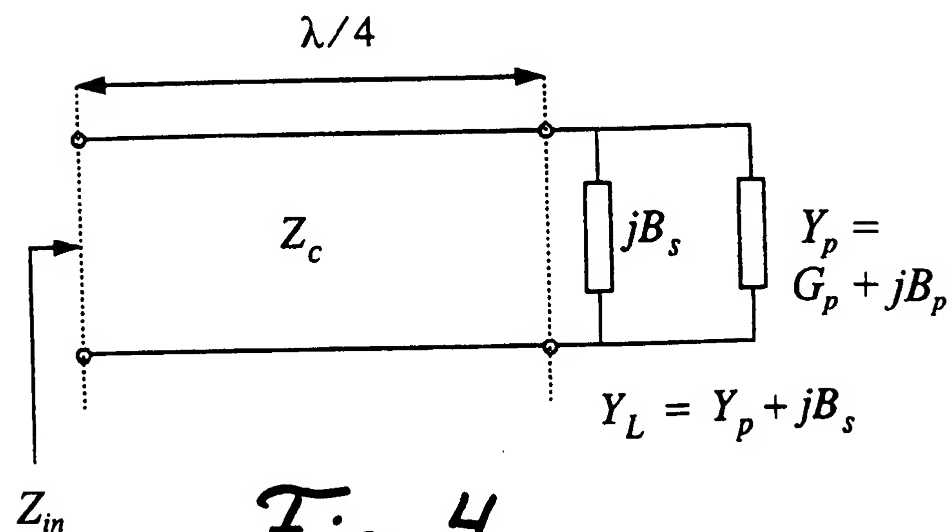


Fig. 4

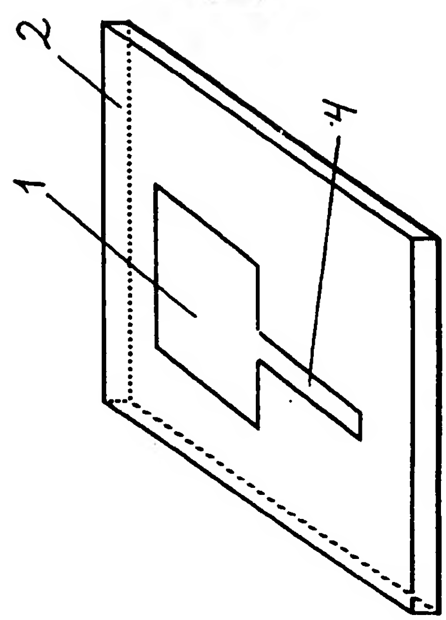


Fig. 2a

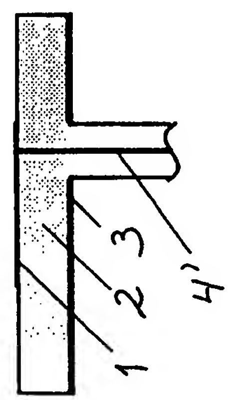


Fig. 2b

(PRIOR ART)

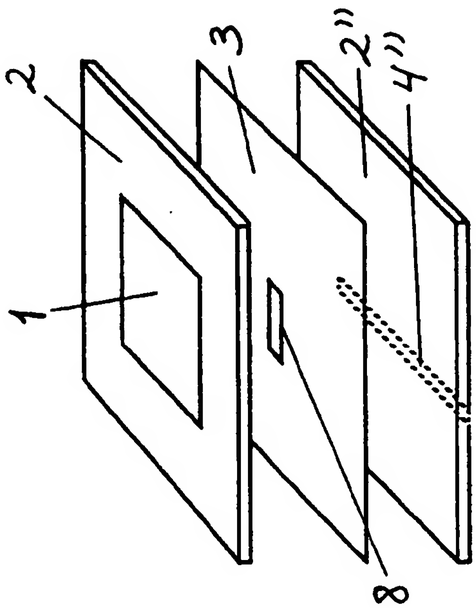


Fig. 2c

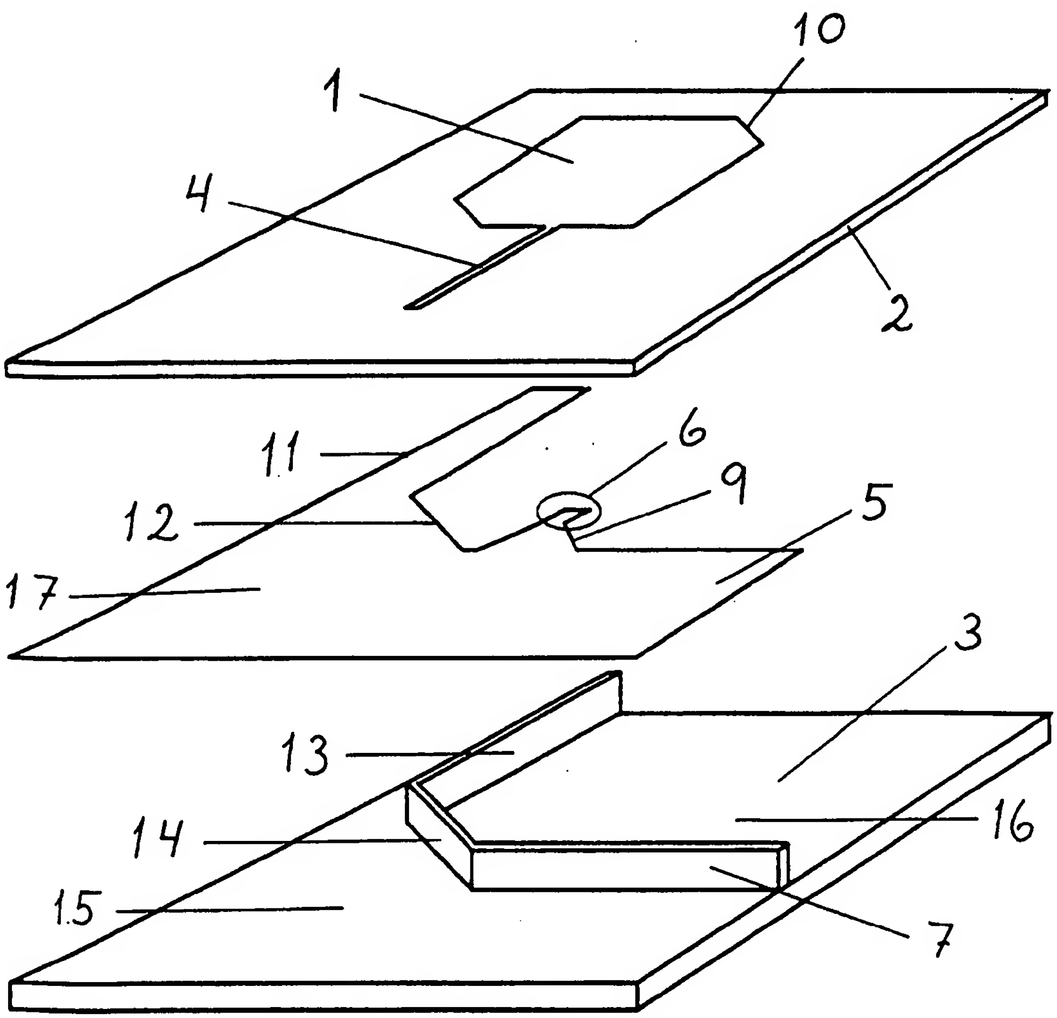


Fig. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/NO 98/00225

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H01Q 1/38
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B. FIELDS SEARCHED

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IPC6: H01Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5241321 A (CHICH-HSING A. TSAO), 31 August 1993 (31.08.93), column 4, figure 2, abstract --	1-13
A	US 4605933 A (FRANK D. BUTSCHER), 12 August 1986 (12.08.86), column 2, figure 1, abstract --	1-13
A	US 4847625 A (FRED J.DIETRICH ET AL), 11 July 1989 (11.07.89), figure 2, abstract --	1-13
A	US 5588198 A (KAZUNARI KAWAHATA ET AL), 31 December 1996 (31.12.96), figures 1a,1b, abstract -- --------	1-13

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
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INTERNATIONAL SEARCH REPORT

Information on patent family members

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5241321 A	31/08/93	NONE	
US 4605933 A	12/08/86	NONE	
US 4847625 A	11/07/89	NONE	
US 5588198 A	31/12/96	JP 7249932 A	26/09/95